1. Overview

The purpose of this FreedomCAR and Vehicle Technologies (FCVT) *Multi-Year Program Plan* is to describe the FCVT Program implementation of future transportation-related technology research and development (R&D) to reduce the nation's dependence upon imported petroleum. This section of the Plan gives background that leads to the justification of the Program and presents a brief overview of the remainder of this document.

Challenges in the 21st Century

The United States faces a host of global and national challenges at the beginning of the 21st Century. Worldwide petroleum depletion and greenhouse gas accumulation (potentially causing climate change) must be faced with the international community. Energy security and local air pollution must be addressed largely within the United States. The motor vehicle, for all of its obvious benefits, is a major contributor to these challenges. Removing the energy and environmental impact of the motor vehicle can result in significant progress on each of these fronts.

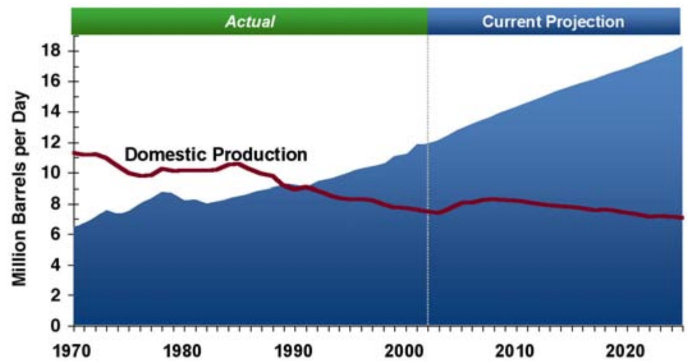

Figure 1. Domestic transportation oil usage exceeded domestic oil production in the recent past.

The nation's energy security is largely dependent on the efficiency of and fuel choices made for its transportation system. The transportation sector, in turn, has a significant influence on the nation's economic and environmental well-being. As Figure 1 shows, the domestic production of oil was exceeded by the domestic oil use for transportation in the recent past. Our highway vehicles alone use more petroleum products than our country produces domestically, and as transportation energy use continues to grow, the situation will only worsen. Domestic oil production has been steadily declining for over two decades, and oil imports are expected to reach 70% of all oil consumed in the United States by 2025. Oil imports have been a growing problem because petroleum resources are distant from most of the world's consumers, unevenly distributed globally, and concentrated in regions with political or environmental sensitivities. Not only is the U.S. demand for oil growing, but the global demand, as indicated by vehicle registration growth (Figure 2), in both industrialized and developing countries is

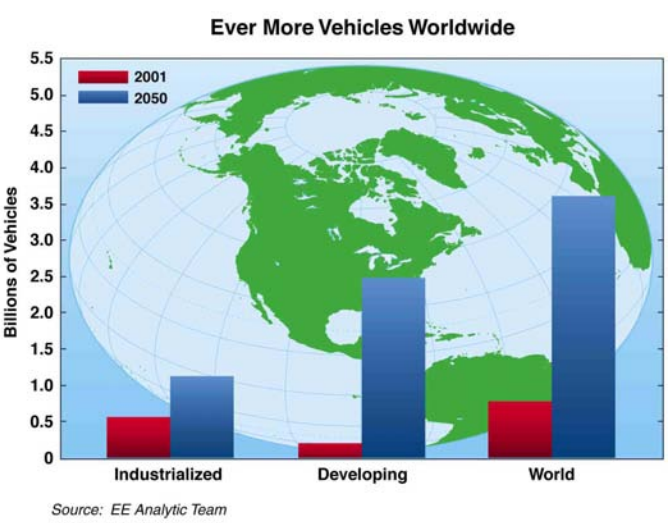

Figure 2. Motor vehicle registration growth.

increasing rapidly—especially in countries such as China and India where the growth in motor vehicles is far outpacing that of the Untied States.

Another part of the challenge is keeping our environment healthy. Transportation accounts for over 30% of all greenhouse gas emissions, for over 80% of carbon monoxide emissions, for over 55% of nitrogen oxides emissions, and for over 40% of volatile organic compound emissions.

Responding to the Challenge

The U.S. Department of Energy's Assistant Secretary for Energy Efficiency and Renewable Energy (DOE/EERE) has R&D programs focused on (1) improving the energy efficiency in our nation's cars and trucks and (2) developing technologies that will eventually lead to automobiles that use no petroleum fuels whatsoever. The R&D will have both a near-term and long-term effect on oil usage. The near-term effect will reduce oil use over the next two or three decades as the energy-efficient technologies become available in vehicles that consumers purchase. The greater long-term effect will be part of the President's Hydrogen Fuel Initiative resulting in cars that are "powered by hydrogen and pollution-free."

Dramatic changes in motor vehicles can take place over the next 30 years, just as they have occurred over the past three decades. Front-wheel drive now dominates powertrain systems; in combination with new materials, it reduced the mass of passenger cars by a thousand pounds in 10 years between the mid-1970s and mid-1980s. Fuel injectors have replaced carburetors; computers control virtually all aspects of the vehicle from engine operation to cruise control to climate conditions; and safety innovations are common now that were unthinkable 30 years ago, from air bags to anti-lock brakes to traction and stability control. And, of course, thanks to improved combustion and catalytic converters and removal of lead from gasoline, light-duty vehicles emit 99% less pollution than they did when vehicles did not have emissions controls. Transportation technology R&D successes have been the leading factor in these improvements. As a result, the U.S. transportation system has vastly improved. The fuel economy for automobiles has increased by over 60%, and fuel economy for light trucks has increased by over 30% during this timeframe. Criteria air pollutants from transportation have also decreased during this same timeframe: emissions of carbon monoxide by over 35%, nitrogen oxides by over 15%, and volatile organic compounds by over 50% from the early 1980s.

The next 30 years may see equally dramatic innovation in vehicles: more hybrid-electric vehicles on the road; increased use of lightweight materials; low-temperature combustion; new ways of reducing parasitic losses; alternative fuels, including the use of hydrogen in conventional engines; and hydrogen-powered hybrid fuel cell vehicles.

The FCVT Role

With its mission to "*develop more energy-efficient and environmentally friendly highway transportation technologies that enable America to use less petroleum*," the Office of FreedomCAR and Vehicle Technologies (OFCVT) supports the R&D that will lead to the adoption of new technologies that reduce the nation's dependency on imported oil, further decrease emissions, and help lead the transition in motor vehicles from conventional fuels and powertrains to hydrogen and hybrid fuel cell vehicles. The FCVT program provides the basis for greater energy efficiency in the mid-term and many of the technologies needed for hybrid fuel cell vehicles to be feasible in the future. *The number one priority of DOE's EERE is the reduction, or removal, of dependence on foreign oil*. The FCVT Program will be the major contributor for the period now until 2030 and perhaps beyond, depending upon the successful advancement of other technologies.

Mission: Develop more energy-efficient and environmentally friendly highway transportation technologies that enable America to use less petroleum.

The number one priority of DOE's EERE is the reduction, or removal, of dependence on foreign oil.

This living document delineates the plan to accomplish this priority. To accomplish its mission, the FCVT Program promotes the development of fuel-efficient motor vehicles and trucks, researches options for using cleaner fuels, and implements efforts to improve energy efficiency. In collaboration with industry, national laboratories, and other research organizations, universities, state governments, and other federal agencies, the FCVT Program supports the R&D of advanced vehicle technologies and fuels that could dramatically reduce and eventually eliminate the demand for petroleum, decrease emissions of criteria air pollutants and greenhouse gases, and enable the U.S. transportation industry to sustain a strong, competitive position in domestic and world markets. Research, development, and validation activities are focused on technologies to reduce oil use by highway vehicles such as cars, light trucks, and heavy vehicles (composed of medium and heavy trucks and buses). Off-highway vehicles (such as vehicles used in construction, mining, and agriculture) and locomotives may benefit from this research because they use engines that are similar to those in heavy-duty trucks. Because the government is not involved in commercialization of the technologies and does not conduct research on the nearest-term applications, which are the purview of industry, the government R&D role is concentrated on higher-risk, longer-term technology development.

Vision: Transportation energy security will be achieved through a U.S. highway vehicle fleet of affordable, full-function cars and trucks that are free from petroleum dependence and harmful emissions without sacrificing mobility, safety, and vehicle choice.

The FCVT vision is that "*Transportation energy security will be achieved through a U.S. highway vehicle fleet of affordable, full-function cars and trucks that are free from petroleum dependence and harmful emissions without sacrificing mobility, safety, and vehicle choice.*" This vision builds on the successful transportation R&D and propels the research on new technologies for transportation.

Several possible pathways exist for securing energy independence in America's transportation system. The Presidential FreedomCAR and Hydrogen Fuel Initiative is one pathway and is designed to reverse America's growing dependence on foreign oil by developing the technology for hydrogen-powered hybrid fuel cell vehicles by the middle of the next decade. FCVT supports this initiative by developing technologies for vehicles to enable petroleum savings during the interim before fuel cells are viable, to establish a technology transition to hybrid fuel cell vehicles and other possible alternate paths, and to apply fuel cells when they become viable for the transportation industry.

The Transition to Hydrogen Hybrid Fuel Cell Vehicles. Many technical and economic barriers currently exist for affordable, mass-produced hydrogen hybrid fuel cell automobiles. Although R&D is under way, with DOE working closely with industry, the research on hybrid fuel cell vehicles is not expected to be completed for another 10 to 12 years; then a business case must be made for this shift to a new fuel and new propulsion system. In the interim, FCVT will support the development of advanced technologies that will be more energy-efficient in the mid-term and, at the same time, provide much of the technology base for the eventual commercialization of hybrid fuel cell vehicles. Because of the more demanding requirements for heavy-truck applications, near-term improvements will focus primarily on improved combustion and reduced parasitic losses to increase efficiency and reduce emissions.

One possible path to a hydrogen future for transportation is illustrated in Figure 3, which also shows how FCVT-supported technologies can become commercialized in the process. The first stage in the transition, as shown in this illustration, is hybridization. FCVT and its predecessor organizations in DOE have supported the development of hybrid vehicle technology for many years, and hybrid vehicles are now being introduced in the U.S. market in limited numbers. Further improvements are expected with advanced combustion techniques and cleaner fuels. Improvements in energy storage and power electronics technologies will continue to make hybrid vehicles, and eventually hybrid fuel cell vehicles, more affordable. Hydrogen internal combustion engines (ICEs) can provide an assist in the transition to a hydrogen transportation system. Auto companies can continue to use existing engine plants, while the hydrogen ICE will encourage hydrogen production and distribution, as well as advances in hydrogen storage. With a hydrogen infrastructure in place and a public that has become comfortable with hydrogen as a fuel for personal vehicles, hybrid fuel cell vehicles can be introduced in the mass market. These technologies may be

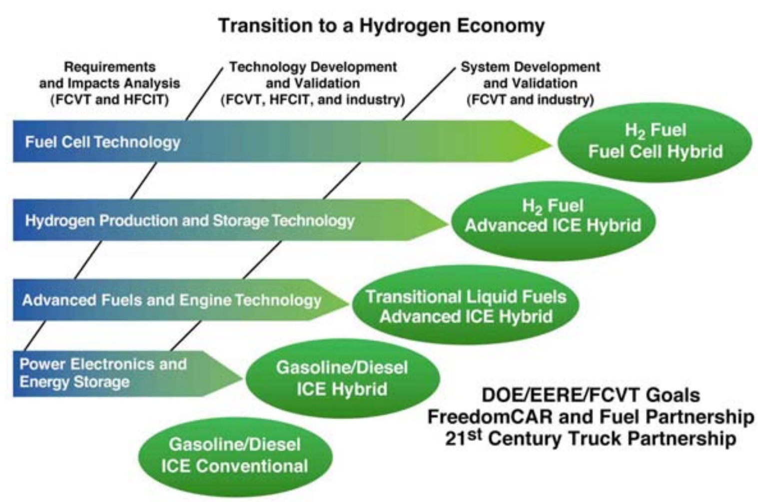

Figure 3. One pathway to the introduction of EERE-supported technologies into commercial products after the FCVT Program has validated the components.

commercialized in a different order; and other technologies being researched in the FCVT Program, such as lightweight materials, may be introduced at any time during the process, as they are not limited to any particular propulsion system. Many different paths exist to a future that provides personal and transport mobility with hydrogen hybrid fuel cell vehicles, and the path and timing will vary for the different types of vehicles. Long-haul trucks, for example, that use the high energy content of diesel fuel and large fuel tanks to minimize refueling times, may adopt fuel cell technology at the latest dates. The common thread is the research that is needed on the many different aspects of the vehicle system to make that future a reality.

The government has a long history of supporting science and fundamental research because the high risk and the long payback period make much of this research unattractive for the private sector to conduct. Much of this research would never be done without government providing the foundation. The role of the government in applied R&D has evolved over time because of the concern about interfering in the commercialization process. However, there are times that national needs provide a compelling case for the judicious support of applied R&D—energy security and climate change being two prime examples. In the case of the automotive research in this Plan (which specifically addresses the national issues of energy and the environment), the approach has been to involve the affected industries to plan the research agenda and identify technical goals that, if met, would provide the basis for commercialization decisions. So the concise description of the approach taken is *"industry-wide collaboration in pre-competitive research, then competition in the marketplace."*

Building on Success. There is a track record of success with the R&D supported by OFCVT and its predecessor organization, the Office of Transportation Technologies. The focus of the research has always been on long-term, high-risk technologies in order to avoid potential conflicts in the commercialization process. Thus the research has been highly regarded and provides a substantial base for furthering energy efficiency in transportation. As one type of measure of success, since the beginning of the Partnership for a New Generation of Vehicles (PNGV) in 1993, the DOE national laboratories have received 16 R&D 100 Awards, 3 *Discover Magazine* Awards, and 6 awards from the Federal Laboratory Consortium for Excellence in Technology Transfer; and one of OFCVT's national laboratory staff was named by *Scientific American* magazine as one of the top 50 research leaders of 2003. Numerous computer codes, to aid tasks ranging from component performance to vehicle systems simulation, have been developed and are widely used by industry and academia. OFCVT also has specialized facilities at the national laboratories that are used by government, industry, and universities for fundamental research and the development of transportation technologies. These specialized facilities include the Advanced Powertrain Research Facility, the Renewable Fuels and Lubricants Laboratory, the High Temperature Materials Laboratory, and the National Transportation Research Center. FCVT and its partners also make extensive use of the Office of Basic Energy Sciences' Combustion Research Facility.

Partnering. The FCVT Program's approach to implementing R&D activities emphasizes jointly funded partnerships with industry and academia to develop and validate technologies. This approach ensures that (1) the nation's best resources are applied to R&D activities, (2) maximum technology transfer takes place, and (3) government resources are leveraged by those of industry.

FreedomCAR Partnership goal: Enable the full spectrum of light-duty passenger vehicles to operate without using petroleum or producing harmful emissions while sustaining freedom of mobility and vehicle choice.

FreedomCAR and Fuel Partnership

In January 2002, the Secretary of Energy and executives of the U.S. automobile industry announced a new cooperative automotive research partnership between the U.S. Department of Energy (DOE) and the auto industry's U.S. Council for Automotive Research (USCAR). This government-industry partnership, designated "FreedomCAR" (in which CAR stands for "Cooperative Automotive Research") supersedes and builds upon the successes of the previous partnership (PNGV). In September of 2003, the FreedomCAR Partnership was expanded to include five major energy companies to address issues related to the supporting fuel infrastructure. It was renamed the FreedomCAR and Fuel Partnership. The FreedomCAR and Fuel Partnership departs from the family sedan "vehicle" focus of PNGV to address the development of advanced technologies suitable for all light-duty passenger vehicles (i.e., cars, SUVs, pickups, minivans). Additionally, compared with PNGV, the government's role in the FreedomCAR and Fuel Partnership has shifted to more fundamental, longer-range, higher-risk technology research. The long-term goal of the FreedomCAR and Fuel Partnership is to enable the full spectrum of light-duty passenger vehicle classes to operate completely free of petroleum and free of harmful emissions while sustaining the driving public's freedom of mobility and freedom of vehicle choice.

OFCVT, in conjunction with USCAR and the five energy companies, is leading the effort, through the FreedomCAR and Fuel Partnership, to develop the technologies that improve vehicle efficiency in the interim and potentially facilitate the transition in the future to hydrogen-powered hybrid fuel cell vehicles. Secretary of Energy Spencer Abraham has designated the OFCVT to lead DOE's vehicle partnerships with the U.S. automotive industry.

The FCVT Program plays a prominent role in the FreedomCAR and Fuel Partnership by conducting R&D to achieve the near- to mid-term goals of the partnership through continued development of advanced technologies that will dramatically reduce the fuel consumption and emissions of all petroleum-fueled, light-duty personal vehicle classes, as reflected in Figure 3. Achieving these near- to mid-term goals is of paramount importance to providing the necessary technologies for hybrid fuel cell electric vehicles.

Figure 4 identifies the organizational structure for the FreedomCAR and Fuel Partnership.

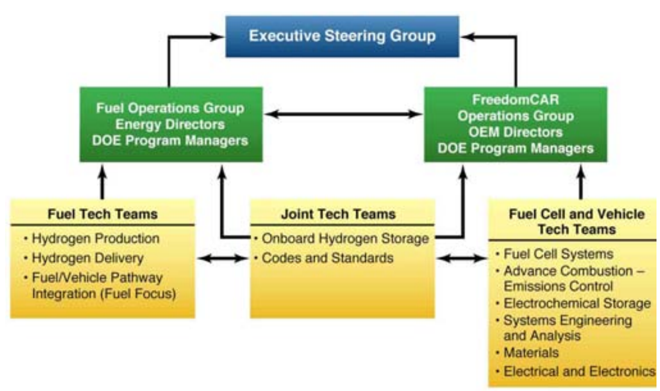

Figure 4. Executive Steering Group for the FreedomCAR and Fuel Partnership. (OEM stands for original equipment manufacturer.)

The role of the FCVT Program in R&D for specific technologies ends once a technology has been validated and a viable technology development pathway has been identified to meet the needs for commercialization. Further discussion of the terms *validated* and *validation* are provided in Section 4.1. Other parts of EERE and DOE, or other federal agencies, may work with industry in fostering the commercialization of the technologies; however, those efforts are not within the scope of this plan.

21st Century Truck Partnership

In November 2002, the Secretary of Energy announced the rejuvenation of the government–industry 21st Century Truck Partnership (21st CTP) to address the R&D needs of commercial vehicles. The ultimate goal of this partnership is to dramatically improve the energy efficiency and safety of trucks and buses while maintaining a dedicated concern for the environment. The 21st CTP is a partnership between the U.S. truck and bus industry and its supporting industries and the federal government. It is for R&D on commercially viable technologies that will dramatically cut the fuel use and emissions of commercial trucks and buses while enhancing their safety and affordability and maintaining or enhancing performance. By developing commercially viable technologies in heavy-duty vehicles, the nation can further reduce its dependence on imported oil and improve air quality.

21st Century Truck Partnership goal: Dramatically improve the energy efficiency and safety of trucks and buses while maintaining a dedicated concern for the environment.

Commercial vehicles provide an important contribution to U.S. economic activity. Historically, the rise in gross domestic product, a measure of economic activity, has been directly linked to the increase in vehicle-miles of commercial transport. There are large efficiency gains to be realized with commercial vehicles, especially heavy-duty transport vehicles, which are more dependent on high-energy-density petroleum-based fuels because of the long distances they travel, their heavier payloads, and their more demanding duty cycles. Therefore, in addition to working on technologies for light-duty passenger vehicles, the FCVT Program addresses R&D of technologies for commercial vehicles through the 21st CTP, and the FCVT Program and this multi-year plan are supportive of this important industry partnership. The FCVT Program is the only program in DOE supporting 21st CTP, and the FCVT Program has the responsibility for managing the government's participation and for conducting and supporting the R&D necessary to meet the partnership's goals. Thus the federal government, led by DOE, and the trucking industry are working together to develop these new technologies and develop prototype production heavy-duty trucks and buses with improved fuel efficiency, reduced emissions, enhanced safety and performance, and lower operating costs. Major participants in the 21st CTP are identified in Figure 5.

Figure 5. Major groups participating in the 21st Century Truck Partnership.

FreedomCAR and Hydrogen Fuel Initiative

In February 2003, President Bush announced the FreedomCAR and Hydrogen Fuel Initiative to develop technologies for (1) fuel-efficient motor vehicles and light trucks, (2) cleaner fuels, (3) improved energy efficiency, and (4) hydrogen production and the nationwide distribution infrastructure needed for vehicle and stationary power plants, to fuel both hydrogen ICEs and fuel cells.

Within EERE, the FCVT Program and the Hydrogen, Fuel Cells, and Infrastructure Technologies (HFCIT) Program have been assigned the responsibility for implementing the FreedomCAR and Hydrogen Fuel parts of the initiative, respectively. The FCVT and the HFCIT Programs are working together closely to implement the initiative, and the interdependency of the two programs is depicted in Figure 6. The expansion of the FreedomCAR and Fuel Partnership to include the energy sector also supports the achievement of the goal of the FreedomCAR and Hydrogen Fuel Initiative. The HFCIT Program efforts in support of the initiative are provided under separate cover in the HFCIT *Multi-Year Research, Development, and Demonstration Plan*. One possible pathway for how the FCVT Program's R&D efforts will contribute to the initiative is provided in Figure 3.

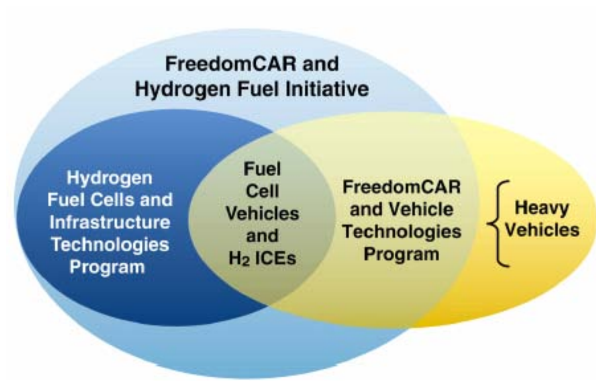

Figure 6. Interdependency of the HFCIT and FCVT.

In addition to these partnerships, achievement of the goals expressed in this *Multi-Year Program Plan* is furthered through the use of laws and regulations relating to intellectual property. Patent and copyright protection of intellectual property associated with the new technologies developed under this plan encourages exploitation of the new technologies by enhancing the competitive position of FCVT Program industrial partners. The degree of intellectual property ownership provided to the industrial partner for new technologies arising under this *Multi-Year*

Program Plan is determined on a case-by-case basis and is commensurate with cost-sharing amounts.

The Partnerships ensure that the federal program has the very best expertise and guidance to fully use resources and adjust to changing situations. Thus FCVT works to develop technologies that can improve our energy security, our environment, and our economy through its partnerships with industry. With the involvement of key industry participants, the commercialization opportunities for FCVT-supported technologies are greatly enhanced.

About the Plan

The *FCVT Multi-Year Program Plan* describes how the FCVT Program will carry out its mission. The plan focuses on R&D during the 2004–2008 time frame, the first five years of the FreedomCAR and Hydrogen Fuel Initiative, although technical targets and technology goals are included to their completion out to the year 2015.

The Plan is organized in the following manner. Section 2 presents the national benefits that will be derived as a result of the conduct of the R&D described herein. Section 3 defines the goals of the FCVT Program and places them in the context of the national need, the National Energy Policy, and the missions of DOE and EERE. Section 4 presents the technical plan for carrying out each of the sub-programs with its major activities and sub-activities. OFCVT has worked with industry to identify seven major sub-programs that support the research needed to develop advanced vehicle technologies to reduce petroleum use. Each of these technology sub-programs may have activities and sub-activities that provide additional focus. To clarify the relationships between the seven technology sub-programs and the performance goals established for automobile and truck applications, a matrix is provided at the end of this chapter.

This section provides an overview of the research program; the details are given in the following chapters. For each sub-program, Section 4 provides the description, status, technology goals, technical targets that have been established, technical barriers, approaches to be taken to address barriers, and critical tasks and milestones for technology development and validation. In some cases, critical decision point go/no-go milestones are presented. Section 5 outlines the management plan for implementing the FCVT Program.

The R&D process to manage the technology development uses established approaches to increase the probability of success.

Finally, the *FCVT Multi-Year Program Plan* is considered to be a living document and, as such, will be updated as required.

The Research and Development Process

FCVT Mission. DOE's overreaching mission is "to advance the national, economic and energy security of the United States; to promote scientific and technological innovation in support of that mission . . ." [1] EERE contributes to that mission by (1) enhancing energy efficiency and productivity and (2) bringing clean, reliable, and affordable energy production and delivery technologies to the

[1] *The Department of Energy Strategic Plan*, U.S. Department of Energy, Washington, D.C., September 30, 2003.

marketplace. As mentioned earlier, the FCVT vision and effort, within those missions, is to support the development of technologies that will achieve transportation energy security through a U.S. highway vehicle fleet consisting of affordable, full-function cars and trucks that are free from petroleum dependence and harmful emissions without sacrificing mobility, safety, and vehicle choice. Although FCVT does not build cars and trucks, it does support the R&D that results in technologies that improve efficiency, use non-petroleum fuels, and reduce emissions. Figure 7 illustrates how each of the FCVT sub-programs focuses on developing advanced technology products that are validated at the vehicle systems level to meet the goals of both the FreedomCAR and Fuel Partnership and the 21st CTP. FCVT addresses the goals of the Partnerships established among the industry and government partners. Priority FCVT goals have been established and performance measures defined to allow continual assessment of progress. These are defined in Section 3, "Goals," and Section 5, "Management Plan." Following is a brief description of targets and barriers and their importance. Following that discussion is a presentation of each sub-program with highlights of its technical goals and rationale.

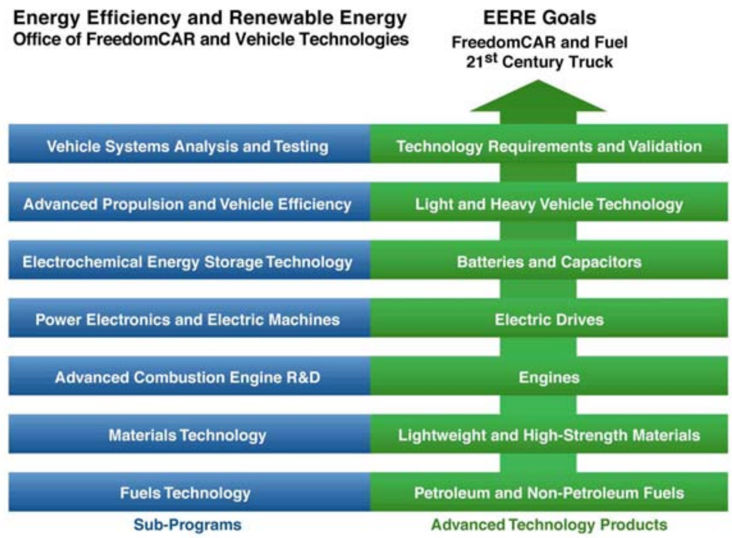

Figure 7. Advanced technology products produced by the FCVT.

Establishing Technical Targets. The key to successful development of advanced vehicle component technologies that enable the attainment of fuel efficiency goals is defining the technical goals, requirements, and targets for those components. The targets guide the technology development and, when the R&D is completed, provide the opportunity to validate the component technologies in a vehicle systems context. The industry partners can then incorporate the technologies into their own vehicle designs. As shown in Figure 7, each of the activities in FCVT has specific outputs that lead directly to advanced technologies needed to meet the goals of the FreedomCAR and Fuel Partnership or the 21st CTP. In the case of Vehicle Systems Analysis and Testing, this sub-program provides the technology requirements for each of the other activities and, at the end, provides validation that the R&D has been successfully completed.

Identifying the Technology Barriers. The relatively low price of gasoline and diesel fuel is an impediment to the development of more fuel-efficient vehicle technologies. In addition, a number of technical barriers limit the performance of the more advanced vehicle technologies. The combination of performance and economic barriers results in an inadequate incentive for industry to develop new technologies when low fuel prices do not encourage a market for fuel-efficient vehicles. Because of these barriers, FCVT works in partnership with industry to develop the technologies that can improve our energy security with the attendant benefits of an improved environment and a better economy. Specific barriers have been identified for each technology area.

The Research Agenda. Each FCVT sub-program has goals designed to meet the overall FCVT goal of developing fuel-efficiency technologies for automotive and truck applications. The research agenda and goals for each of the sub-programs are summarized in the following paragraphs and treated in detail in Section 3, "Goals," and throughout the technical sections of this plan. The matrix given on the last page of this overview provides a quick view of how the FCVT goals relate to the FCVT research sub-programs. This matrix is intended to show quickly which technology areas are major contributors to achieving a specific goal, which are providing some limited contribution to the goal, and which have an insignificant contribution.

Vehicle systems analysis and testing. This sub-program provides an overarching vehicle systems perspective to the technology R&D activities of DOE's FCVT and HFCIT Programs. It uses analytical and empirical tools to model and simulate potential vehicle systems, validate component performance in a systems context, benchmark emerging technology, and validate computer models. Hardware-in-the-loop allows components to be controlled in an emulated vehicle environment. Laboratory testing then provides measurement of progress toward FCVT technical goals and eventual validation of DOE-sponsored technologies at the Advanced Powertrain Research Facility for light- and medium-duty vehicles and at the ReFUEL Facility for heavy-duty vehicles. For this sub-program to be successful, extensive collaboration with the technology development activities in FCVT and HFCIT is required in both analysis and testing. The analytical results of this sub-program are used to estimate national benefits and/or impacts of DOE-sponsored technology development. The section of this overview titled "Managing the Research" presents more information on this sub-program.

Advanced propulsion and vehicle efficiency improvements. This sub-program is composed of four major, related activities: Light Hybrid Propulsion Systems, Heavy Hybrid Propulsion Systems, Light Vehicle Ancillary Systems, and Heavy Vehicle Parasitic Loss Reduction. Much of the focus in this area has been on hybrid technology and has stimulated worldwide interest in hybridization to improve fuel economy. Achieving the goal of ***developing an ICE powertrain system costing $30/kW, having a brake engine efficiency of 45%, and meeting emission standards*** represents a 50% improvement in efficiency over current automobiles. The research focus now is optimization, cost reduction, and minimization of the fuel economy penalty of even stricter emissions controls. In addition, the advanced propulsion sub-program will address the FreedomCAR and Fuel Partnership goal of developing a cost-competitive hydrogen ICE, which serves the dual purpose of reducing vehicle emissions and beginning the transition to hydrogen hybrid fuel cell vehicles. Fuel savings in heavy-duty vehicles (Class 3–8 trucks and buses) can also be facilitated by hybrid technologies but will require modification of components and control strategies as determined by system-level modeling and optimization.

Vehicle efficiency can also be improved by reducing the fuel needed to power the light-duty vehicle ancillary systems (primarily the passenger cabin climate control) and by reducing the parasitic energy losses (aerodynamic drag, friction and wear, idling) and improving energy efficiency through regenerative shock absorber devices, use of a diesel fuel reformer to avoid coking, and engine thermal management for heavy-duty vehicles.

Parasitic loss reduction will be especially important in the truck applications; here, research is focused on auxiliary load electrification, aerodynamic and rolling resistance reduction, friction and wear reduction, under-hood thermal management, and efficient climate control. A priority FCVT goal is to ***develop technologies that reduce parasitic energy losses, including losses from aerodynamic drag, from 39% of total engine output in 1998 to 24% in 2006***. The average aerodynamic drag coefficient of a current-technology Class 8 truck is 0.625. One of the goals of the Heavy Vehicle Parasitic Loss Reduction activity is ***by 2012, develop and demonstrate advanced technology concepts that reduce the aerodynamic drag of a Class 8 highway tractor-trailer combination by 20%***. This activity is also performing research that will, ***by 2012, develop and demonstrate technologies that reduce essential auxiliary loads by 50% (from the current 20 horsepower to 10 horsepower) for Class 8 tractor-trailers***.

It is estimated that the construction and integration of a hybrid electric vehicle drive system currently adds $10,000 to the cost of a light-duty vehicle. Heavy-duty hybrid electric vehicles, such as buses, typically cost two times more than conventional-drive vehicles. To help bring the cost of these vehicles into a more competitive range, the Heavy Hybrid Propulsion Systems activity has the ***2012 technology goal to develop a drive unit that has 15 years of characteristic life and costs no more than $50/kW peak electric power rating***. This activity is also directing research at improving the fuel economy of heavy vehicles and has the additional goal ***by 2012, develop and demonstrate a heavy hybrid propulsion technology that achieves a 60% improvement in fuel economy, on a representative urban driving cycle, while meeting regulated emissions levels for 2007 and thereafter***.

Energy storage technologies. There are three closely interrelated activities within the energy storage sub-program: Battery Development, Applied Battery Research, and Long-Term Exploratory Research. Energy storage devices, especially batteries, have been identified as critical enabling technologies for advanced fuel-efficient cars and trucks. The applications for advanced energy storage range from battery-electric vehicles to hybrid-electric vehicles to hybrid fuel cell vehicles. Battery research for automotive applications has been ongoing for over 25 years. However, even after significant effort, the demanding requirements for high-energy-density batteries for electric vehicles remain to be met, although high-power batteries for hybrid electric vehicles have achieved significant success. Research has now been consolidated in the short term on meeting the challenges of lithium-ion batteries, with a longer-term exploratory research activity focused on fundamental cell development. OFCVT works in close partnership with the United States Advanced Battery Consortium, a collaboration of automotive companies, to meet the specific requirements for motor vehicles. Energy storage is critical for the long-term goal of hybrid fuel cell vehicles as well as for near-term hybrid vehicle improvements.

Full battery system development is under way with R&D on lithium-sulfur batteries for electric vehicles and lithium-ion batteries for both high energy density for electric vehicles and high power density for hybrid vehicles. Applied battery research is conducted on lithium-ion chemistry cost, battery life, and abuse tolerance. Long-term exploratory battery research is focused on the fundamental problems: chemical instabilities that impede the development of advanced batteries, anodes, cathodes, electrolytes, diagnostics, and modeling. Energy storage systems for hybrid electric vehicles typically cost $2000 and are major contributors to the $10,000 incremental cost of the vehicles. A priority FCVT goal is ***to reduce the production cost of a high-power 25-kW battery for use in light-duty vehicles from $3000 in 1998 to $500 in 2010***; an intermediate goal of $750 in 2006 would enable cost-effective entry of hybrid vehicles (cost targets are estimated at a production level of 100,000 batteries per year).

Heavy vehicle energy storage systems, like those for light vehicles, are characterized by high cost. The goal, ***by 2012, develop an energy storage system with a 15 year life and cost of less than $25/kW peak electric power rating***, will result in a system cost reduction of two to four times.

Advanced power electronics and electric machines. Advanced power electronics (e.g., inverters, capacitors, motor-controllers, and other power management or interface electronics) are key components for hybrid electric vehicles and ultimately for hybrid fuel cell vehicles. The focus is to improve performance, develop low-cost materials, and improve thermal management systems to produce higher power. The vehicle environment is particularly demanding because of the requirement for high reliability under rugged conditions, coupled with the need for low cost, light weight, and minimal volume. This sub-program is composed of three major activities: Power Electronics, Electric Motors and Generators, and Power Management and Integration.

The research in power electronics includes fundamental R&D; development of an integrated chip controller (without external circuitry) to reduce cost; development of a bifunctional dc/dc converter to interconnect the fuel cell's high-voltage bus with the low-voltage bus for auxiliary loads; development of a lightweight, low-cost inverter to convert dc power from a fuel cell or battery to ac power for the electric motor; and research on capacitors as alternatives to inverters. Concurrently, R&D is being conducted on high-performance, low-cost materials and thermal management systems for electric motors and generators, with special emphasis on permanent magnet motors. Researchers are also investigating advanced component modeling and fabrication and manufacturing techniques to integrate motor and power control technologies and thereby reduce the size and cost of power management systems. A priority FreedomCAR and Fuel Partnership goal is ***to develop by 2010 an integrated electric propulsion system with a 15-year life that is capable of delivering at least 55 kW of power for 18 seconds and 30 kW continuously at a system cost of $12/kW peak***. Achieving this goal will reduce the cost of the traction motor and inverter drive system from its current $22/kW and will significantly enhance the cost-competitiveness of hybrid electric vehicles.

Advanced combustion engine R&D. In the near- and mid-term, research that provides dramatically improved engine combustion efficiency can have a significant effect on petroleum consumption. Combustion research is crosscutting in that there are synergies between light-duty, medium-duty, and heavy-duty engine research. Work in this area addresses the need to expand the fundamental knowledge of engine combustion and technical barriers related to emission control, engine controls (ignition timing, rate of heat release, transients and cold starts), and costs. The approach is designed to achieve a greater understanding of in-cylinder combustion and emissions formation, the effectiveness of exhaust aftertreatment technologies, and fuel formulation strategies. There are five major activities within this sub-program: Combustion and Emission Control, Light Truck Engine R&D, Heavy Truck Engine R&D, Waste Heat Recovery, and Health Impacts.

Combustion and emissions control applies to both current light-duty and heavy-duty vehicles. This research will focus on three areas concurrently: (1) in-cylinder combustion and emissions control, (2) exhaust aftertreatment, and (3) fuel formulation with the objective of finding the most cost-effective approach to optimizing engine efficiency and performance while reducing emissions to meet future U.S. Environmental Protection Agency standards. In addition to fundamental combustion research and applied research in low-temperature combustion regimes—such as homogeneous-charge, compression-ignition (HCCI) engines—work will be undertaken on hydrogen-fueled ICEs, since they will provide an interim hydrogen powertrain technology leading to the ultimate goal of hydrogen hybrid fuel cell vehicles. Current hydrogen-fueled ICEs are not emissions-compliant when operating at a power density that is competitive with that of liquid-fueled engines. The goal to develop ***an ICE powertrain system operating on hydrogen with a cost target of $45/kW by 2010 and $30/kW in 2015, having a peak brake thermal efficiency of 45% and meeting emissions standards*** will address this issue. Achieving this goal is shared by the Light Hybrid Propulsion Systems activity, the Combustions and Emissions Control R&D activity, and the HFCIT Program.

A longer-term goal in this research area is the development of a cost-effective waste heat recovery system that overcomes barriers such as system packaging (size), scale-up of some new devices (e.g., quantum well thermoelectrics), and system durability. Waste heat recovery could enable diesel thermal efficiency of 55%.

Another activity in this area is exploration of the scientific relationships between mobile emissions from new vehicle-fuel technologies and any quantifiable health hazards, in order to preclude the introduction of high-efficiency engines and their requisite fuels that could have unintended human health impacts.

A priority FCVT goal is to improve the efficiency of ICEs from 30% to 43% by 2010 for light-duty and from 40% to 55% by 2012 for heavy-duty applications while meeting cost and durability constraints and reducing emissions to near-zero levels. Achieving the goal represents a 50% improvement in efficiency over current automobiles. This efficiency improvement could yield similar fuel economy improvements in conventional and hybrid electric vehicles. Increasing truck engine efficiency from the current 40% to 55% will increase Class 8 truck fuel economy by 20–30%.

Materials technologies. To improve vehicle efficiency, high-strength, lightweight materials will be needed for the frame, body, chassis, and powertrain systems for cars, light trucks, heavy trucks, and buses. Concept vehicles are already demonstrating the significant progress that has been made in reducing vehicle mass, but the materials and manufacturing costs remain high. The technical targets are focused on affordability while meeting performance, safety, and recyclability objectives. Materials of interest include carbon fiber, titanium alloys, magnesium alloys, metal matrix composites, and thermoplastic resin systems. Primary metal production, advanced reinforcement technologies, joining, design methodologies, and glazing are some additional issues that are being addressed, depending on the type of material. Research in this area is divided into five major activities: Automotive Lightweighting Materials, High Strength Weight Reduction, High Temperature Materials Laboratory, Automotive Propulsion Materials, and Heavy Vehicle Propulsion Materials. As a user facility, contributions of the High Temperature Materials Laboratory include work with numerous industries, universities, and government laboratories on a wide range of applications of transportation materials. The facility provides state-of-the-art materials characterization for fundamental research.

Weight reduction not only contributes to greater vehicle fuel efficiency but also can offset the weight increases that may result from some advanced powertrain systems. Although vehicle weight reduction directly increases fuel economy, the cost of lighter materials prevents large-scale movement away from steel. The Automotive Lightweighting Materials activity is funding research on materials such as carbon fiber, which is currently a factor of three too expensive but offers spectacular weight reduction potential. Research in automotive lightweight materials is focused on the dramatic weight reductions for body and chassis components without compromising vehicle cost, performance, safety, or recyclability. The overall goal for this research on automobile materials is ***by 2012, develop and validate advanced material technologies that will enable reductions in the weight of body and chassis components by at least 60% and overall vehicle weight by 50% (relative to 1997 comparative vehicles). A priority FCVT goal is to reduce the production cost of carbon fiber from $12 per pound in 1998 to $3 per pound in 2006.*** The carbon fiber cost figures are based on production levels of 5,000,000 pounds per year or more.

Automotive propulsion materials research is focused on improving the operating efficiency and reducing the costs of engine systems and power electronics through advanced materials research. Carbon foam is being explored for power electronics cooling applications, and long-life diesel particulate filters are being developed. The Heavy Vehicle Propulsion Materials activity is designed to provide new or improved materials for heavy-duty engines that meet the high durability and reliability requirements of these vehicles. Development of materials that reduce erosion and corrosion in heavy-duty engines caused by exhaust gas recirculation is one goal; development of materials that help engines achieve efficiencies of over 50% while meeting future emissions standards is an example of another.

High-strength weight reduction materials research concentrates on reducing parasitic energy losses due to the weight of heavy vehicles. Areas of focus are the cab, chassis, and drivetrain; and the relevant materials are advanced engineered materials such as metal matrix composites and ultralight materials such as laminates and foams. Tractor-trailer combinations, like automobiles, will benefit from the application of lighter materials, and reducing the parasitic energy losses of heavy-duty vehicles is the vision of the High Strength Weight Reduction Materials activity. The High Strength Weight Reduction Materials activity addresses a priority FCVT goal: ***by 2010, reduce the weight of an unloaded tractor-trailer combination from the current 23,000 lb (2003) to 18,000 lb, a reduction of 22%***. For trucks that operate at their load limit, there is not a direct increase in fuel economy, but there is a fuel economy benefit on a "ton-mile" basis.

Fuels technology. The Fuels Technologies sub-program supports research that provides vehicle users with fuel options that are cost-competitive and that enable high fuel economy, deliver lower emissions, and contribute to petroleum displacement. Advanced Petroleum-Based Fuels (APBF) and Non-Petroleum-Based Fuels (NPBF) R&D are activities that are undertaken to enable current and advanced combustion systems to be more efficient while meeting future, more-stringent emissions standards. APBFs consist of highly refined petroleum fuels, possibly blended with non-petroleum components derived from renewable resources. In contrast, NPBFs include fuels derived primarily from agricultural products, biomass, natural gas, or coal. The goals of the Fuels Technologies subprogram are to develop technologies and fuel specifications with the potential both to allow displacement of 5% of petroleum from near-term technology (i.e., direct-injection diesel) and to sustain that 5% displacement in the transition to mid- to long-term advanced combustion technology (e.g., HCCI engines). There is also a New Technologies Impacts activity to ensure that any new fuel formulation does not adversely affect the environment, avoiding problems such as those created in the past by tetraethyl lead and MTBE.

The activities of the Fuels Technologies R&D and Advanced Combustion Engine R&D subprograms will be coordinated to such an extent that fuel and combustion technologies will be *co-developed* for emerging advanced combustion regimes. This integration of these activities will allow a full exploitation of the potential for high-efficiency, clean, in-cylinder combustion. Fuels optimized for advanced-combustion-regime engines are likely to be somewhat different from current gasoline or diesel fuels, although the extent of the difference is not yet known. Tighter control of variation among fuels may be sufficient to enable some level of operation, but maximizing the potential benefit of such regimes is likely to require a more extensive understanding of the impact of fuel properties on combustion than is available today. To gain such an understanding will require an improved database on detailed fuel chemistry and its impact on combustion, rather than the bulk property-based correlations of fuel blendstocks currently available in the open literature. To that end, an FCVT goal is to **identify fuel formulations optimized for use in 2007–2010 technology diesel engines that incorporate the use of non-petroleum-based blending components with the potential to achieve at least a 5% replacement of petroleum fuels**. In addition, a key goal of the Fuels Technologies subprogram is **by 2010, to identify fuel formulations optimized for use in advanced combustion engines (2010–2020 technology) providing high efficiency and very low emissions, and validate that at least 5% replacement of petroleum fuels could be achieved in the following decade**. This latter goal will ensure that petroleum displacement gains achieved with near-term engine technologies will not be lost with the introduction of high-efficiency, advanced combustion technologies. To assess the impacts of promising advanced fuel formulations, the New Technology Impacts effort will seek to identify, analyze, quantify, and thereby avoid potentially deleterious ecosystem impacts of new fuels, specifically fuels that are envisioned to displace significant quantities of petroleum.

Managing the Research

OFCVT has established four technical teams to plan, coordinate, and manage the technology development needed to meet the technical targets set jointly by FCVT and its industry partners. They are the Vehicle Systems Team (which includes any field testing), the Advanced Materials Team, the Fuels Team (which also addresses lubricants, as well as meeting the requirements of the Energy Policy Act), and the Engine and Emissions Control Team. Figure 8 illustrates the process by which these four teams are able to meet the goal of the Office: develop vehicle technologies that can be successfully commercialized and improve the nation's energy security by dramatically reducing our dependence on petroleum.

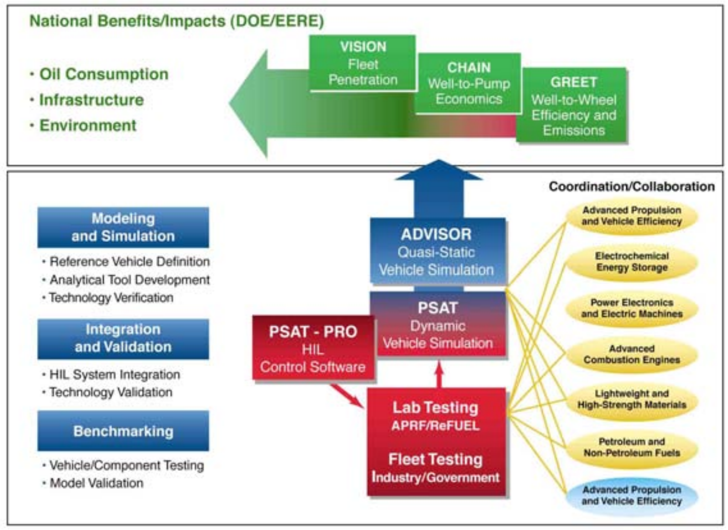

Figure 8. Process by which the four technical teams meet the goals of OFCVT.

As shown in the bottom portion of the chart, the R&D process begins by developing technology requirements and setting technical targets. The ADVISOR model is used to quickly estimate the fuel-saving potential of any new vehicle propulsion system and develop technical targets. The PSAT model then uses dynamic analysis of vehicle performance and efficiency to support detailed component design and hardware development. At this point, each of the FCVT technology teams, plus the HFCIT teams for hydrogen and fuel cell R&D, has the technical direction to conduct the appropriate technology development that will lead to components that are expected to perform in a vehicle systems context so that the energy efficiency targets can be met. The PSAT-PRO model enables these components to be tested and validated in a hardware-in-the-loop environment. The hardware that is developed can be validated in the laboratory or in field tests; after successful performance testing, it will be ready to be "harvested" by industry and commercialized. At any step along the way, a series of macro-models (GREET, CHAIN, and VISION) can provide national-level impact analysis of the total energy cycle, infrastructure requirements, and emissions and oil consumption, ensuring that the benefits of the research exceed the taxpayer investment in these advanced vehicle technologies.

To assess progress toward achievement of the goals, intermediate milestones and performance measures have been established. Technologies developed by FCVT are evaluated to validate that the component/subsystem technologies developed by FCVT meet the technical targets assigned to them.

Vision for the Future

FCVT supports the development of more energy-efficient and environmentally friendly transportation technologies, with the help of its industry partners, for the immediate needs and future needs of America's transportation system. Development of the new technologies addresses the challenges of energy independence, petroleum depletion, and greenhouse gases and local emissions. FCVT R&D will enable U.S. automotive and truck industries to be more competitive.

In addition, the petroleum savings would make oil price shocks less likely. Success in developing and marketing advanced energy-efficient technologies in America's cars and trucks will provide significant benefits for the nation.

- **Energy Security:** The President has stated that if fuel cells are developed to their full potential, we could reduce our demand for oil by 11 million barrels of oil per day by 2040. FCVT includes research on advanced automotive and truck technologies (e.g., hybrid powertrains, power electronics, energy storage, lightweight materials) that will provide the transition to hydrogen-powered hybrid fuel cell vehicles. FCVT technologies will also enable fuel savings during the transition before fuel cells are ready to be commercialized in the transportation sector. By 2040, the savings from timely introduction of technologies from the FCVT Program that are complementary to fuel cells are estimated to be from 4.5 to nearly 6 million barrels per day. Should there be a delay in hybrid fuel cell vehicle commercialization, the fuel savings potential for FCVT technologies would continue to grow, as those technologies would already be in the marketplace.

- **Improved Environment:** On a per-vehicle basis and in terms of the total energy cycle, hybrid vehicles can reduce greenhouse gas emissions by nearly 50% compared with conventional vehicles, providing additional environmental benefits during the transition to the ultimate goal—hybrid fuel cell vehicles operating on hydrogen. In addition, the fuel economy improvements achieved by heavy-duty vehicles will contribute to a reduction in greenhouse gas emissions, as carbon emissions from petroleum fuel are directly related to fuel economy.

- **Economic Competitiveness**: The global automotive and truck markets are extremely competitive because of the economic benefits of high-wage manufacturing jobs and spillover benefits to the broader manufacturing sector. FCVT activities in advanced technology development are conducted jointly with USCAR, a consortium of U.S. car makers. An even more diverse consortium representing the heavy-duty truck industry is another research partner with FCVT. One of the direct benefits of FCVT research will be to enable U.S. companies to be more competitive with lower-wage countries by leading in the development of advanced technologies. In addition, the reduction of petroleum use in transportation will reduce the nation's dependence on oil imports from sensitive regions of the world, lessening the opportunities for oil price shocks and the attendant economic consequences.

Meeting the goals for both the FreedomCAR and Fuel Partnership and the 21st CTP will provide the pathway for the United States to dramatically change its energy use and petroleum dependence, greatly reducing emissions and the transportation sector's contribution to greenhouse gases, while sustaining mobility and the freedom of vehicle choice. This is a vision that will benefit all citizens. The pursuit of cleaner, more-efficient vehicles today and emissions-free, petroleum-free vehicles tomorrow is a national goal set by the President and is important to the nation's energy, environmental, and economic future. The research agenda in this plan leads to this vision of the future.

OFCVT Technology/Goal Matrix

Each of the technology areas in OFCVT has research activities that are directly related to one or more of the goals in the FreedomCAR and Fuel Partnership or 21st CTP. The following matrix shows the relationships.

Technology is a major contributor to achieving this goal ●

Technology contributes to achieving this goal ○

Technology is not a contributor to achieving this goal

Goals	Vehicle Systems Analysis and Testing	Adv. Propulsion and Efficiency	Energy Storage Technologies	Power Electronics & Electric Machines	Adv. Combustion Engine R&D	Materials Technologies	Fuels Technologies
Electric Propulsion Systems							
Achieve a 15-year life and the capability to deliver at least 55 kW for 18 seconds and 30 kW continuous at a system cost of $12/kW peak	○	○	○	●		○	
Internal Combustion Engines							
Improve the efficiency of internal combustion engines from 30% (2002 baseline) to 43% by 2010	○	○		○	●	○	○
Electric Energy Storage							
Reduce the production cost of a high-power 25-kW battery for use in light vehicles from $3000 in 1998 to $500 in 2010	○		●	○		○	
Materials and Manufacturing							
Achieve a 50% reduction in the weight of vehicle structure and subsystems, affordability, and increased use of recyclable/renewable materials	○				○	●	
Reduce the weight of a tractor-trailer from 23,000 lb in 2003 to 18,000 lb in 2010 (a 22% reduction)	○					●	
Hydrogen Internal Combustion Engine							
Achieve $45/kW by 2010 and $30/kW in 2015, along with a peak efficiency of 45%, while meeting or exceeding emissions standards (shared responsibility)	○	●		○	●	○	
Engine Systems							
Increase the thermal efficiency of heavy truck engines to 55% while reducing emissions to near-zero levels.	○	●		○	●	○	○
Develop diesel fuel that uses renewables and other non-petroleum agents, achieves high efficiency and low emissions, and displaces petroleum fuels by 5% by 2010	○	○			○		●
Heavy Duty Hybrids							
Develop a drive unit that has 15 years of characteristic life and costs no more than $50/kW peak electric power rating	○	●	○	○		○	
Develop heavy hybrid propulsion technology that achieves a 60% improvement in fuel economy, on a representative urban driving cycle, while meeting regulated emissions levels for 2007 and thereafter	○	●	○	○	●	○	○
Develop an energy storage system with 15 years of characteristic life that costs no more than $25/kW peak electric power rating	○	○	●	○		○	
Parasitic Losses							
Reduce heavy truck parasitic losses (e.g., aerodynamics, ancillary systems) from 39% of engine output in 1998 to 24% in 2006	●		○	○		○	
Reduce the aerodynamic drag of a Class 8 highway tractor-trailer combination by 20% (from a current average drag coefficient of 0.625 to 0.5)	●					○	
Reduce essential auxiliary loads by 50% (from the current 20 horsepower to 10 horsepower) for Class 8 tractor-trailers	●			○		○	